

Assessing Surface Water Quality Degradation in Response to Urban Pollution Dynamics in Man, Côte d'Ivoire

Franck Michaël Zahui^{1,2*}, Prince Othniel Augou¹, Amichalé Jean Cyrille Beda^{1,2}, Jean-Marie Pétémanagnan Ouattara^{3,4}, Lacina Coulibaly^{3,4}

¹Department of Agronomic, Forestry and Environmental Engineering, University of Man, Man, Côte d'Ivoire

²Central Analytical Laboratory, University of Man, Man, Côte d'Ivoire

³Department of Sciences and Environment Management, Nangui Abrogoua University, Abidjan, Côte d'Ivoire

⁴Laboratory of Environment and Aquatic Biology, Nangui Abrogoua University, Abidjan, Côte d'Ivoire

Email: *michael.zahui@univ-man.edu.ci

How to cite this paper: Zahui, F.M., Augou, P.O., Beda, A.J.C., Ouattara, J.-M.P. and Coulibaly, L. (2026) Assessing Surface Water Quality Degradation in Response to Urban Pollution Dynamics in Man, Côte d'Ivoire. *Natural Resources*, 17, 281-304. <https://doi.org/10.4236/nr.2026.1710016>

Received: September 17, 2026

Accepted: October 20, 2026

Published: October 23, 2026

Copyright © 2026 by author(s) and Scientific Research Publishing Inc. This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

Surface waters in urban areas are subject to increasing anthropogenic pressures, driven primarily by poor waste management, domestic discharges, and agricultural activities. This study assesses the water quality of the Koh River and Beau Séjour Lake in Man (Côte d'Ivoire) to identify main pollution sources and evaluate environmental degradation using the Organic Pollution Index (OPI), Heavy Metal Pollution Index (HPI), and Water Quality Index (WQI). Nineteen sampling points were monitored, including fourteen on the Koh River and five across Beau Séjour Lake. Physico-chemical, chemical, and metallic parameters were determined through field measurements and laboratory analyses. Solid waste dumping was identified as the predominant pressure, occurring at 91.7% of the river stations and 80% of the lake stations. Market gardening and discharges from showers and septic tanks also represent significant pollution sources along the river. The results reveal pronounced organic pollution in the river, with critical degradation at stations S5, S8, and S10, while the lake exhibits severe localized degradation at stations S2 and S3. Although the risk of heavy metal contamination remains generally low, a critical threshold was breached at river station S1 (HPI = 154.9). The WQI confirms severe water quality deterioration: thirteen of the fourteen river stations and two lake stations are classified as unsuitable for use. Overall, these findings demonstrate that organic pollution, driven by diverse and intensive anthropogenic pressures, is the primary factor degrading these urban water bodies.

Keywords

Water Quality, Urban Pollution, Anthropogenic Pressures, Indices (OPI, HPI, WQI), Côte d'Ivoire

1. Introduction

Rapid and often poorly controlled urbanization exerts increasing pressure on aquatic environments located within or near urban areas [1] [2]. The expansion of built-up areas and the intensification of human activities are accompanied by a rise in the production of solid and liquid waste, as well as domestic, agricultural, and artisanal discharges [3]. When collection, sanitation, and treatment systems are insufficient, these inputs can reach watercourses and water bodies directly or indirectly, causing alterations in their physico-chemical and chemical properties and, ultimately, a deterioration of their quality [1] [2]. Urban hydrosystems thus serve as primary recipients of the pressures exerted by human activities [1].

This issue is of particular importance in sub-Saharan Africa, where urban growth often occurs in a context marked by deficiencies in sanitation and waste management [3]. Surface waters are subject to increasing pressures, notably related to urbanization, domestic discharges, as well as agricultural and livestock activities [4] [5]. The combination of these different pressures can promote the accumulation of organic matter, nutrients, and contaminants in aquatic environments, compromising both their ecological functions and their uses [4] [5].

In Côte d'Ivoire, several studies have already highlighted the degradation of surface water quality in secondary cities facing increasing urban pressures, particularly in Bouaké [6] [7]. These studies show that urban expansion and poor waste management can be significant factors in the deterioration of water resources [6] [7]. The city of Man fits into this dynamic. Located in the west of Côte d'Ivoire, it is experiencing urban development associated with various human activities and has a hydrographic network that notably includes the Koh River and Beau Séjour Lake. These two aquatic environments, directly integrated into the urban space, are exposed to various anthropogenic pressures likely to influence their quality.

The Koh River flows through several sectors of the city and is subject to various uses by the riverside populations, notably for certain agricultural activities, while the surroundings of Beau Séjour Lake are also occupied by human activities. In these areas, the deposition of solid waste, domestic discharges, market gardening, livestock farming, and other activities can constitute potential sources of pollutants [5]. The diversity and spatial distribution of these pressures are likely to produce different levels of degradation depending on the sectors and environments [2]. Therefore, the challenge is not only to determine whether the waters are degraded, but also to characterize this degradation and examine its relationship with the spatial dynamics of urban pressures.

This approach requires considering multiple dimensions of water quality simultaneously. Physico-chemical and chemical parameters allow for the characteri-

zation of different components of the state of the environment, but their individual interpretation does not always provide a synthetic reading of the situation [8]. The Organic Pollution Index (OPI) thus allows for the assessment of the level of pollution associated particularly with organic matter and nitrogen compounds [9], while the Heavy Metal Pollution Index (HPI) enables the synthesis of the contamination level related to several metallic elements [10] [11]. The Water Quality Index (WQI), for its part, integrates multiple parameters in order to provide an overall assessment of water quality [8] [12] [13].

In this context, the present study aims to assess the degradation of surface water quality of the Koh River and Beau Séjour Lake in relation to urban pollution pressures in the city of Man. More specifically, it involves identifying the main potential sources of pollution, characterizing the levels of organic pollution and metal contamination, and evaluating the overall quality of both environments using the OPI, HPI, and WQI, in order to highlight the most degraded areas and contribute to better management of these surface water resources within the city of Man.

2. Material and Methods

2.1. Study Area

The study was conducted in the municipality of Man, located in western Côte d'Ivoire, in the Tonkpi region, between 7°20' and 7°35' north latitude and 7°25' and 7°45' west longitude (**Figure 1**). The municipality is situated in a mountainous terrain, with elevations reaching approximately 1117 m. The area has a climate characterized by annual rainfall exceeding 1700 mm and an average temperature of approximately 24°C. The river system is primarily dominated by the Kô and N'Zo rivers and their tributaries, several of which are seasonal [14]. The municipality of Man had a population of 241,969 according to the 2021 General Population and Housing Census [15]. Its settlement pattern is organized into several urban neighborhoods. The area's socioeconomic activities are based primarily on agriculture, supplemented by trade, handicrafts, and rock crushing. Urban development and the intensification of human activities are contributing to increased interactions between the population and surface water resources [14].

Two aquatic environments were thus selected for this study: the Koh River and Beau Séjour Lake. The Koh River is a tributary of the N'Zo and flows for approximately 9 km through the city of Man. It passes through several urban areas, including Blokoss, Libreville, Dioulabougou, and Camp SEA. The river is thus an important element of the urban hydrographic landscape and interacts directly with human activities along its banks. In particular, it is used by local residents for vegetable gardening during the dry season, contributing to the local production of fresh vegetables. Beau Séjour Lake, meanwhile, is an artificial body of water covering approximately 1.72 ha, located southwest of the city, near the Biankouma Corridor Road. Its water supply depends mainly on rainfall. Its shores are home to fishing and restaurant activities, among others, giving it a certain degree of local socioeconomic importance.

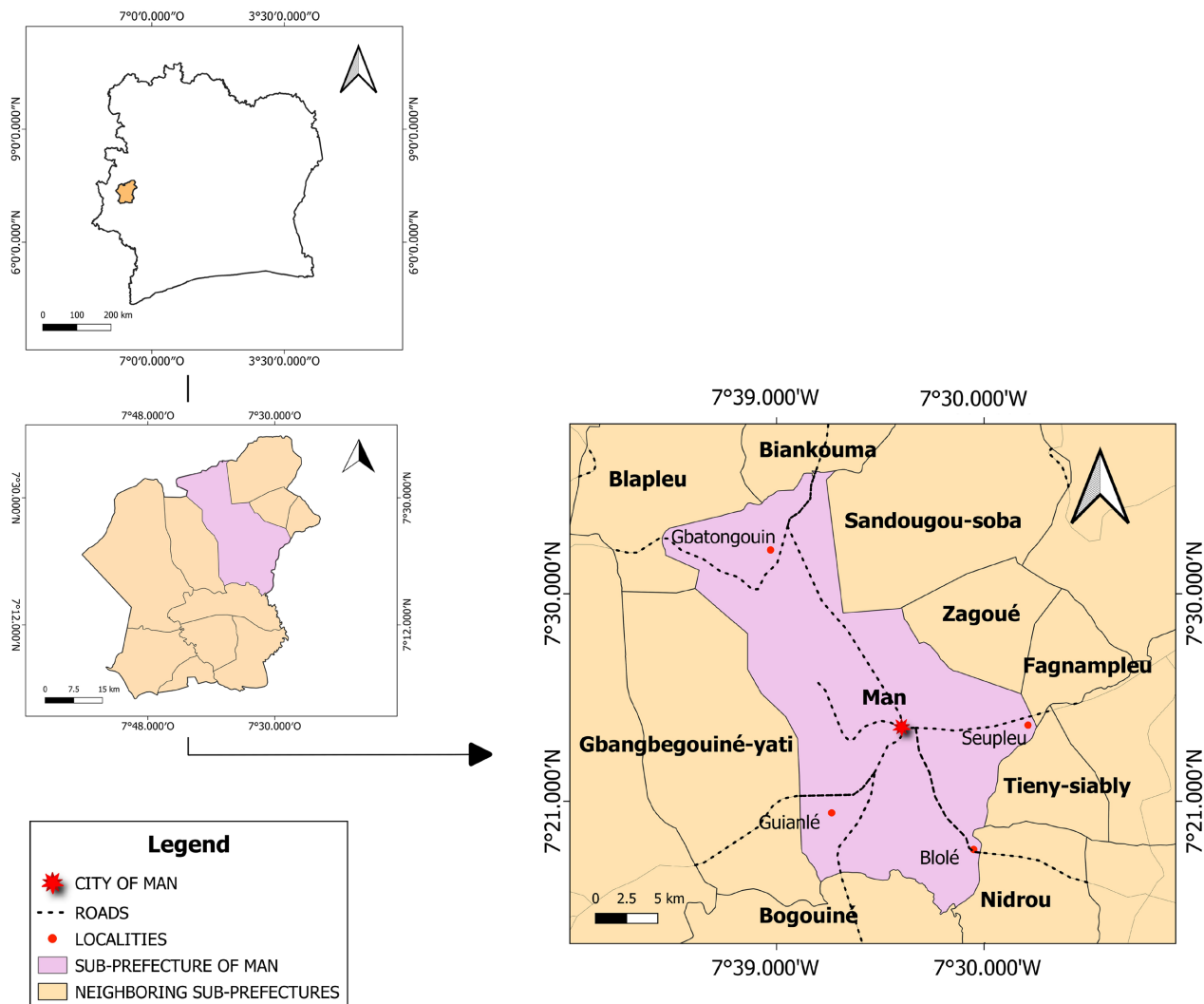


Figure 1. Geographical location of the city of Man.

2.2. Identification of Pollution Sources, Selection of Monitoring Stations, and Analysis of Parameters

A preliminary field survey was carried out in January 2026 around the two hydro systems: the Koh River and Beau Séjour Lake in order to identify activities that might constitute potential sources of pollution. The observations covered a radius of 25 meters around the bodies of water in question. A source of pollution was considered to be present when an activity, a facility or a discharge associated with urban practices located within the study area was deemed capable of significantly affecting the quality of aquatic environments. The survey was therefore used to determine the locations of sampling points along the Koh River and Beau Séjour Lake. The main sources observed included solid waste dumps, domestic discharges from showers and septic tanks, vegetable farming, washing activities, and animal husbandry and slaughter. Sampling stations were then selected to cover the various environmental contexts and levels of pressure identified.

A total of 19 sampling stations were selected, including 14 on the Koh River and

5 around Beau Séjour Lake (Figure 2). Along the river, the distribution of these stations makes it possible to monitor changes in water quality in different neighborhoods of the city. Station S1 is located at the entrance to the “Si tu veux” neighborhood; stations S2 through S4 are in the Blokoss area. Station S5 is located at the intersection of Libreville and Domoraud, while S6 is situated between Dioulabougou and Domoraud. Station S7 is in Saari, stations S8 and S9 are in Camp Séa, and S10 is near the slaughterhouse. Further downstream, S11 is located in the Lycée sector, and stations S12 through S14 are in the KGB sector, toward the southern outskirts of the urban area. Stations S13 and S14, where no potential sources of pollution were identified during the survey, were selected to assess changes in water quality after the river flows through the main urbanized areas. Around Beau Séjour Lake, the five stations were distributed along the various shores based on the observed anthropogenic pressures, so as to achieve spatial coverage that is sufficiently representative of local pollution.

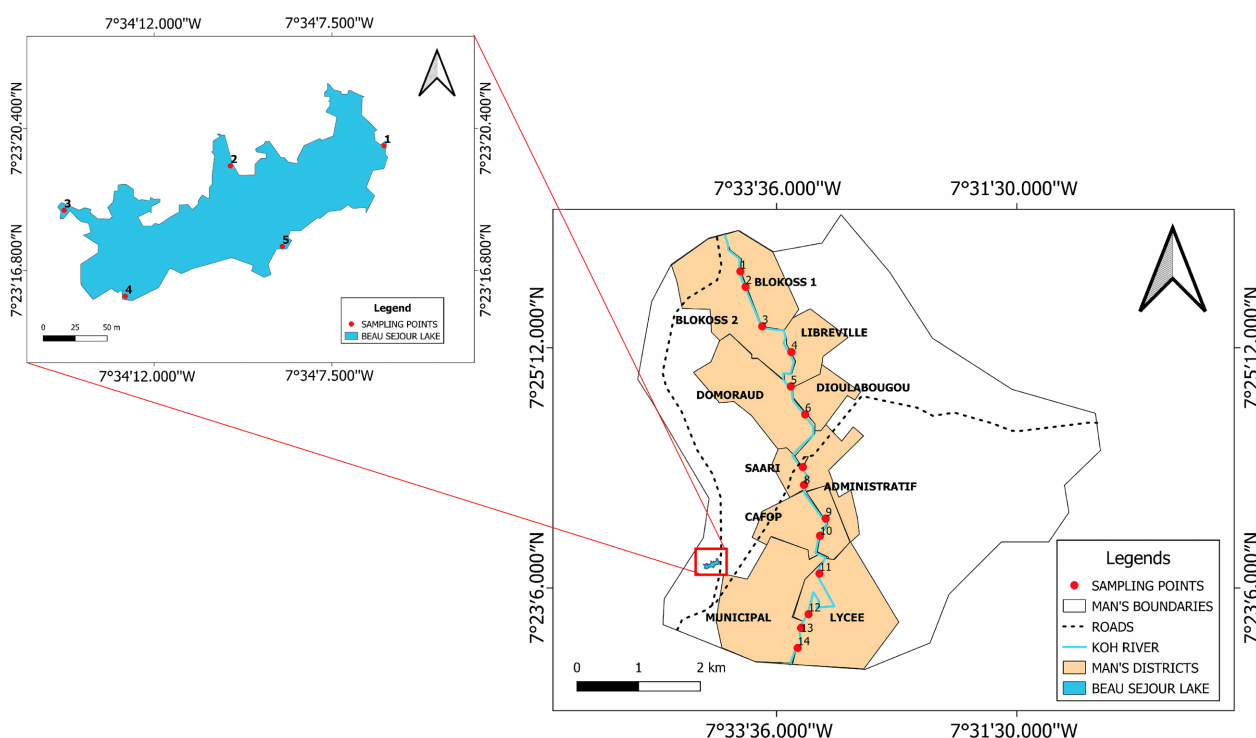


Figure 2. Distribution of sampling stations along the Koh River and Beau Séjour Lake.

Samples were taken during the dry season as part of a single sampling campaign carried out in February 2026, in order to minimise the effects of dilution caused by rainfall during the wet season. Consequently, this approach made it possible to mitigate the effects of diffuse water pollution during the rainy season and thus to assess, in broad terms, the actual impact of the sources of pollution found in the vicinity of these bodies of water, taking into account the activities of the local communities. The sampling campaign was carried out at the 14 stations on the Koh River and the 5 stations on Beau Séjour Lake. At each station, three samples were

taken. For the river, this consisted of one sample from the left bank, one from the center of the channel and the last from the right bank. At the lake, the three samples were collected from the same sampling point within a 5-metre radius. These samples were analysed separately for each parameter in the laboratory. For the in situ measurements, three separate readings were also taken using the multi-parameter instrument. Samples were collected using 1-litre polyethylene bottles, which were stored in an airtight cool box at approximately 4°C. These were transported to the laboratory within 24 hours for analysis. In situ measurements were taken for pH, temperature, turbidity, dissolved oxygen and electrical conductivity. These measurements were taken using a HANNA HI9829 multi-parameter analyser. Nutrient levels were determined by molecular absorption spectrometry in accordance with the following standardised methods: NF T90-013 for nitrites, NF T90-045 for nitrates, NF T90-015 for ammonium, NF T90-023 for orthophosphates, and total phosphorus. The BOD₅ of the water samples was determined using Ox-iTop manometers in accordance with standard NF T90-103. To do this, the samples were kept in the dark for five days. The concentrations of heavy metals lead, cadmium, chromium, copper and zinc were determined using inductively coupled plasma optical emission spectrometry in accordance with the methods described in ISO 11885.

2.3. Methods for Calculating Indices to Assess the Quality and Frequency of Pollution Sources

2.3.1. Organic Pollution Index (OPI)

Organic water pollution was assessed using the Organic Pollution Index (OPI) proposed by Leclercq [16]. This index is based on the classification of several pollution indicator parameters into different quality classes (Table 1). Each parameter is assigned a class number between 1 and 5 based on its concentration, and the OPI corresponds to the average of the resulting classes.

$$OPI = \left(\sum_{k=1}^n (C_k, \dots, C_i) / n \right) \quad (1)$$

where C_i corresponds to the class number assigned to parameter i and n to the total number of parameters considered. High OPI values indicate low organic pollution, while low values indicate higher pollution (Table 2).

Table 1. Classification grid for the parameters used to calculate the OPI [16].

Parameters Classes	BOD ₅ mgO ₂ /L	NH ₄ ⁺ mgNH ₄ ⁺ /L	NO ₂ ⁻ µgNO ₂ ⁻ /L	PO ₄ ³⁻ µg PO ₄ ³⁻ /L
1	>15	>6	>150	>900
2	10.1 - 15	2.5 - 6	51 - 150	251 - 900
3	5.1 - 10	1 - 2.4	11 - 50	76 - 250
4	2 - 5	0.1 - 0.9	6 - 10	16 - 75
5	<2	<0.1	<5	<15

Table 2. Water classification grid based on OPI values [16].

OPI Valuations	Level of Organic Pollution	Colour
4.6 - 5.0	None	
4.0 - 4.5	Low	
3.0 - 3.9	Moderate	
2.0 - 2.9	Strong	
1.0 - 1.9	Very strong	

2.3.2. Heavy Metal Pollution Index (HPI)

The level of heavy metal contamination in the waters of the Koh River and Beau Séjour Lake was assessed using the Heavy Metal Pollution Index (HPI), originally proposed by Mohan *et al.* [10]. The calculation focused on copper (Cu), zinc (Zn), lead (Pb), cadmium (Cd), and chromium (Cr). These elements were selected primarily because of their potential presence in poultry manure [17], which is used in the city's agricultural practices. Calculated using a weighted arithmetic mean method, the HPI is commonly used to assess metal contamination in surface water and groundwater [10] [18]. For each metal, a sub-index Q_i was determined using Equation (2) in order to bring the different concentrations onto a common scale for comparison.

$$Q_i = \sum_{i=1}^n \frac{M_i - I_i}{S_i - I_i} \times 100 \quad (2)$$

where M_i represents the measured value of the parameter, S_i the corresponding maximum permissible limit, and I_i the ideal value.

A unit weight W_i was then assigned to each metal based on its maximum permissible limit and its toxicity level. This weight was determined using the inverse of the reference guideline value used in this case, that of the WHO [19], in accordance with the relationship presented in Equation (3).

$$W_i = \frac{k}{S_i} \quad (3)$$

The final value of the heavy metal pollution index (HPI) was calculated using Equation (4).

Table 3. Water classification grid based on Heavy Metal Pollution Index (HPI) values.

Classes HPI	Risk of Pollution
HPI < 100	Low
HPI = 100	Threshold
HPI > 100	High

$$HPI = \frac{\sum_{i=1}^n WiQi}{\sum_{i=1}^n Wi} \quad (4)$$

In this study, the assessment of the risk of metal pollution is based on a direct comparison of HPI values against the critical threshold of 100. An HPI below 100 corresponds to a low risk, a value of 100 indicates a critical threshold, and a value above 100 indicates a high risk of metal pollution (**Table 3**).

2.3.3. Water Quality Index (WQI)

The Water Quality Index (WQI) was used to assess the overall condition of the waters of the Koh River and Beau Séjour Lake. Originally developed by Horton [12] and later refined by Brown *et al.* [13], this index combines several quality parameters into a single value. It thus classifies water into five categories: excellent, good, poor, very poor, and unsuitable.

The WQI was calculated using ten parameters: pH, electrical conductivity (EC), temperature, biochemical oxygen demand (BOD₅), phosphates (PO₄³⁻), ammonium (NH₄⁺), nitrites (NO₂⁻), nitrates (NO₃⁻), copper (Cu), and zinc (Zn). The weighted arithmetic mean method described by Brown *et al.* [13] [20] was applied. This approach assigns each parameter a relative weight Wi based on its importance for water quality. The weights were determined using reference guideline values, according to Equation (5).

$$Wi = \frac{k}{Si} \quad (5)$$

where k is the proportionality constant, calculated using the following equation:

$$k = \frac{1}{\sum_{i=1}^n Si} \quad (6)$$

where n represents the number of parameters under consideration, and Si is the maximum permissible value for parameter i according to the WHO guideline values [19], expressed in the appropriate unit.

For each parameter, a Qi quality scale was then calculated by relating the measured concentration to the corresponding guideline value and then multiplying the result by 100, in accordance with Formula (7).

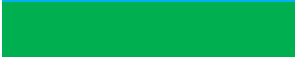
$$Qi = \frac{Ci}{Si} \times 100 \quad (7)$$

where Qi denotes the quality index for the parameter, Ci its measured concentration, and Si the maximum reference value. The overall water quality index was finally calculated using Equation (8).

$$WQI = \frac{\sum_{i=1}^n WiQi}{\sum_{i=1}^n Wi} \quad (8)$$

The values obtained were used to classify the water into five quality classes, as shown in **Table 4**.

Table 4. Classification and potential uses of water according to the Water Quality Index (WQI) [20].

WQI Values	Water Quality Classes	Colour
[0 - 25[	Excellent	
[25 - 50[	Good	
[50 - 75[	Bad	
[75 - 100[	Very Poor	
[100 and More[	Contaminated Water	

2.3.4. Frequency of Occurrence of Sources of Pollution

The frequencies of occurrence of the various sources of pollution were calculated on the basis of the first twelve monitoring stations (S1 to S12). This exclusion is justified by the specific role assigned to these last two stations within the study framework. Indeed, S13 and S14 were specifically added in order to assess the condition of the river as it flows out of the town of Man and, more specifically, to measure the residual impact of upstream sources of pollution on the water quality. Unlike the first twelve stations, they are therefore not intended to indicate the direct presence of sources of pollution. The inclusion of S13 and S14 in the calculation of occurrence frequencies could therefore have introduced a bias into the estimate of the frequency of the various categories of pollution sources. The fact that these stations were deliberately chosen to exclude directly observable sources of pollution would, in effect, have been treated as if such sources were absent from the calculation, whereas these stations were specifically selected to assess the residual effects of pollution originating upstream. The calculated frequencies were therefore determined solely on the basis of those stations at which sources of pollution are directly observable and can be identified. The percentages obtained should therefore be interpreted as the frequency with which the various categories of pollution sources occur amongst the monitoring stations where their presence can actually be observed, and not as a measure of their overall contribution to the river's pollution. Equation (9) was used to determine the frequency of occurrence of each source.

$$F = \frac{ns}{nst} \times 100 \quad (9)$$

where F represents the frequency of occurrence of a source of pollution, ns the number of stations at which this source was observed, and nst the total number of stations included in the analysis, namely 12.

2.4. Data Analysis

The data collected at the various stations were organised according to the two environments studied: the Koh River and Beau Séjour Lake. Samples were collected in February 2026. At each station, samples were taken in three field replicates. Follow-

ing analysis, the results obtained for each parameter measured both in situ and in the laboratory were averaged. The averages obtained for the parameters at each station were then used for statistical analysis and for calculating the indices. For each physico-chemical, chemical and heavy-metal parameters, descriptive statistics were calculated separately for the different environments in order to determine the means, standard deviations and the minimum and maximum values specific to each. These statistical analyses made it possible to compare the levels and variability of the parameters between the two environments and between the monitoring stations. As there were no national reference values applicable to raw surface water available for this study, the WHO guideline values for drinking water [19] were used, for the relevant parameters, as benchmarks for comparison. These enable the measured concentrations to be compared against established benchmarks for the protection of human health, but do not constitute ecological quality standards for surface water. Their use in calculating indices may therefore lead to a stricter assessment of water quality against these benchmarks, without in itself determining the water's suitability for a particular use. Previous studies have also used WHO values as comparative benchmarks in the assessment of surface water [21] [22]. Finally, the values measured at each monitoring station were used to analyse spatial variations, to identify the areas with the highest or lowest concentrations, and to calculate the OPI, HPI and WQI indices. The monitoring stations were then ranked according to their levels of organic pollution, metal contamination and overall water quality.

3. Results and Discussion

3.1. Results

3.1.1. Spatial Dynamics of Pollution Sources along the River and around Beau Séjour Lake

The survey of pollution sources revealed a greater variety of such sources along the Koh River than on the shores of Beau Séjour Lake. Six categories of sources were identified in the vicinity of the river (**Table 5**).

Table 5. List of pollution sources encountered at each sampling point on Beau Séjour Lake and along the Koh River (* = presence of a pollution source).

Sampling Points		Sources of Pollution					
Stations	Neighbourhoods/ Locations	Market Gardening	Solid Waste	Fittings/ Septic Tanks	Laundrettes	Slaughterhouse	Livestock Farming
Beau Séjour Lake							
S1	Beau Séjour Lake		*				
S2							*
S3			*				
S4			*				
S5			*				

Continued

Koh River					
S1	Si tu veux	*	*	*	*
S2	Blokoss	*	*	*	*
S3	Blokoss	*	*	*	
S4	Pt Blokoss (CHR)	*	*	*	
S5	Pt Libreville-Domoraud	*	*	*	
S6	Pt Dioulabougou-Domoraud	*	*	*	*
S7	Pt Saari	*	*	*	
S8	Camp Sea 1	*	*		
S9	Camp Sea 3	*			
S10	Abattoir		*		*
S11	Lycée		*		
S12	KGB		*		
S13	KGB				
S14	KGB				

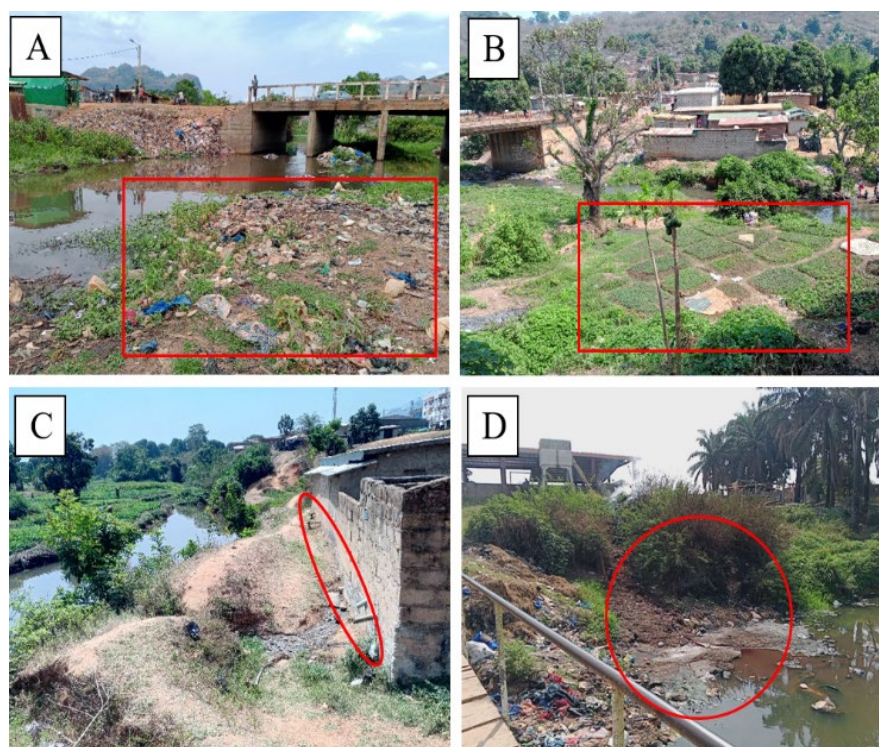


Figure 3. Illustration of some sources of pollution found along the Koh River: (A): solid waste; (B): market gardens; (C): shower drains; (D): slaughterhouse effluent.



Figure 4. Illustration of the main sources of pollution found around Beau Séjour Lake: (A): solid waste; (B): pig farm effluent.

These include market gardening, solid waste disposal, connections to showers and septic tanks, laundry activities, animal slaughter and livestock farming (**Figure 3**). Around Beau Séjour Lake, the main pressures observed were solid waste disposal and livestock farming (**Figure 4**).

3.1.2. Frequency of Occurrence of Sources of Pollution in the Two Environments

Figure 5 shows the frequency of occurrence of sources of pollution along the river and at Beau Séjour Lake. It can be seen that solid waste deposits are the most frequently observed source, occurring in 91.7 per cent of cases along the Koh River and in 80 per cent of cases around Beau Séjour Lake. Along the river, market gardening and connections from showers and/or septic tanks were also widely represented, with frequencies of 75 per cent and 58.3 per cent, respectively. Slaughtering, livestock farming and laundries, on the other hand, were less common at the various sampling points along the river.

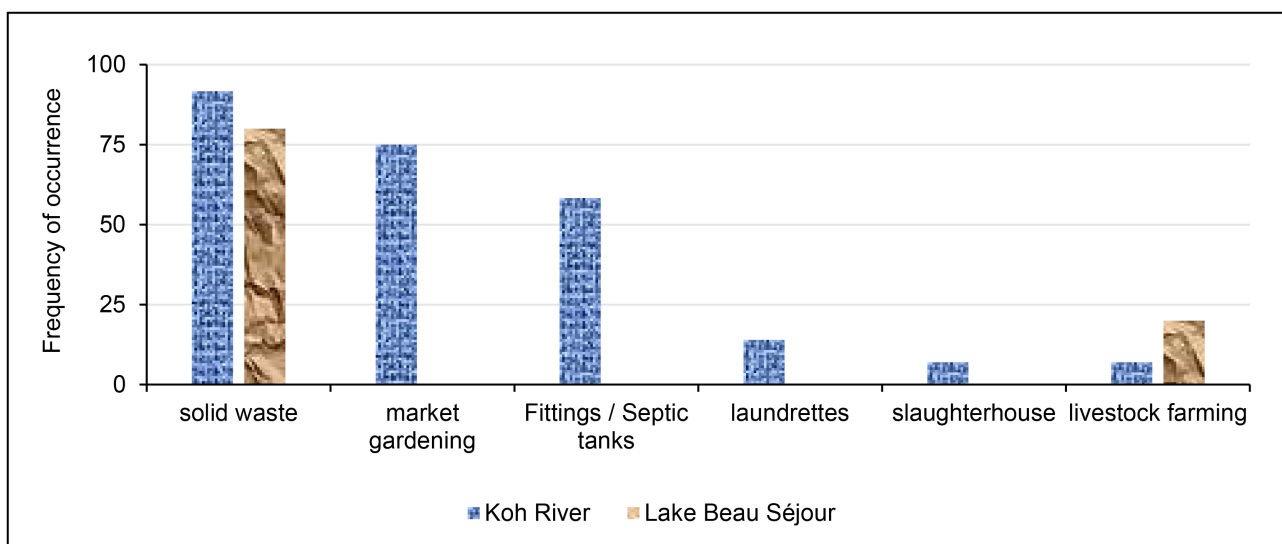


Figure 5. Frequency of occurrence of pollution sources along the Koh River and around Beau Séjour Lake.

3.1.3. Upstream and Downstream Profile of Pollution Sources

The distribution of pollution sources along the Koh River revealed an overall decrease in anthropogenic pressures from upstream to downstream (**Figure 6**). The average number of sources fell from around three per station between S1 and S7 to around one source per station between S8 and S14. Stations S1, S2 and S6 had the highest number of sources identified, whilst no sources were observed at stations S13 and S14.

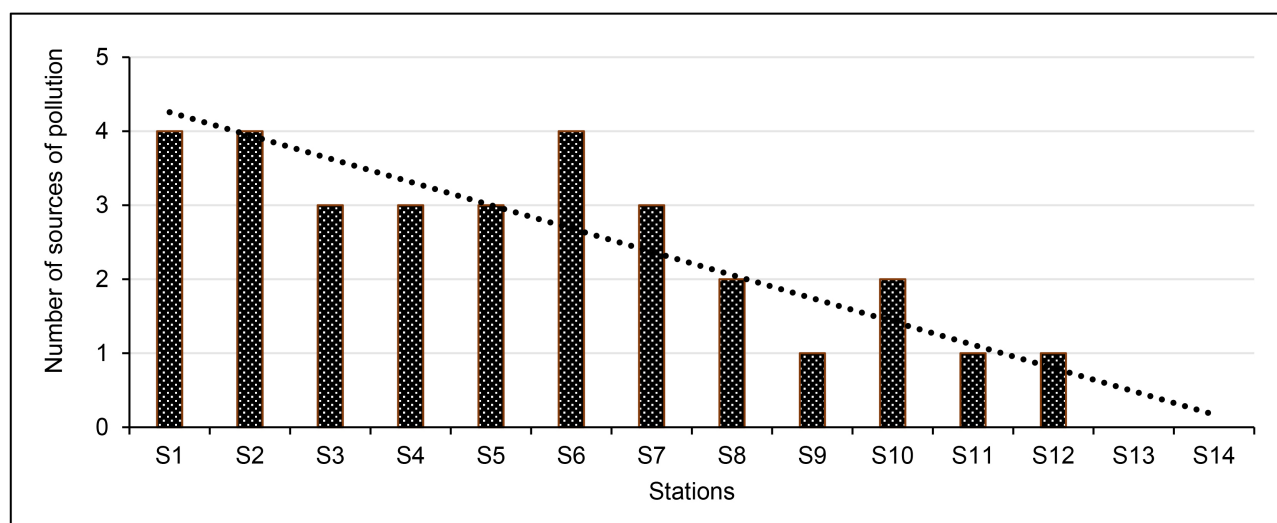


Figure 6. Number of pollution sources identified at each station along the Koh River.

3.1.4. Physico-Chemical, Chemical and Metallurgical Characteristics of the Waters of the Koh River and Beau Séjour Lake

The physico-chemical and metal parameters presented in **Table 6** highlight differences between the two study sites. The average pH is similar in both water bodies, with values of 7.65 ± 0.39 in the river and 7.55 ± 0.60 in the lake, both falling within the range recommended by the WHO (6.5 - 8.5). The average temperature is slightly higher in the lake ($28.11^\circ\text{C} \pm 0.18^\circ\text{C}$) than in the river ($26.47^\circ\text{C} \pm 0.98^\circ\text{C}$), whilst remaining within the indicative range of 25°C - 30°C proposed by the WHO. Dissolved oxygen concentrations are very low in both environments, averaging $0.81 \text{ mg/L} \pm 0.70 \text{ mg/L}$ in the river and $0.40 \text{ mg/L} \pm 0.46 \text{ mg/L}$ in the lake. Electrical conductivity, on the other hand, is higher in the lake, where it reaches $104.8 \text{ }\mu\text{S/cm} \pm 21.9 \text{ }\mu\text{S/cm}$ compared with $63.1 \text{ }\mu\text{S/cm} \pm 7.1 \text{ }\mu\text{S/cm}$ in the river, whilst remaining low and below the guideline values generally reported by the WHO. Average turbidity, meanwhile, is higher in the river ($37.6 \text{ NTU} \pm 16.2 \text{ NTU}$) than in the lake ($23.1 \text{ NTU} \pm 3.0 \text{ NTU}$), with average values recorded above the guideline value of 5 NTU.

The parameters associated with organic and nutrient pollution generally show higher and more variable concentrations on the river side. Average ammonium (NH_4^+) concentrations reach $59.5 \text{ mg/L} \pm 50.9 \text{ mg/L}$, whilst BOD_5 is $192 \text{ mg/L} \pm 295 \text{ mg/L}$. These values far exceed the respective guideline values of 1.5 mg/L and 40 mg/L . Nitrates (NO_3^-), with an average concentration of $148.8 \text{ mg/L} \pm 177.6 \text{ mg/L}$,

also frequently exceed the guideline value of 50 mg/L. By contrast, nitrite (NO_2^-) and phosphate (PO_4^{3-}) concentrations, with mean values of $89.84 \mu\text{g/L} \pm 153.38 \mu\text{g/L}$ and $2,582.53 \mu\text{g/L} \pm 7,250.46 \mu\text{g/L}$, respectively, remained predominantly below the WHO reference thresholds at most monitoring stations in both environments.

With regard to metallic elements, the concentrations of lead (Pb), cadmium (Cd), zinc (Zn), chromium (Cr) and copper (Cu) remain largely within the WHO guideline values. However, the maximum levels observed are generally higher in the river, particularly for zinc and copper, indicating greater spatial variability in metal contamination in this environment.

Table 6. Minimum, maximum and average values for the physico-chemical, chemical and metallic parameters of the waters of Beau Séjour Lake and the Koh River, together with the associated WHO guideline values (SD = Standard deviation).

Parameters	Units	Koh River			Beau Séjour Lake			WHO Guideline Values ^[19]
		Average ± SD	Min	Max	Average ± SD	Min	Max	
Physico-Chemical Parameters								
pH	-	7.649 ± 0.388	7.110	8.240	7.550 ± 0.597	6.510	8.000	6.5 - 8.5
Temperature	(°C)	26.47 ± 0.983	25.00	27.70	28.11 ± 0.181	27.80	28.24	25°C - 30°C
Electrical Conductivity	µS/cm	63.07 ± 7.054	50.00	73.00	104.80 ± 21.92	69.00	129.00	400 - 2000 µS/cm
Turbidity	(NTU)	37.56 ± 16.20	15.60	62.50	23.06 ± 3.030	19.10	26.00	5 NTU
Dissolved Oxygen	mgO ₂ /L	0.807 ± 0.704	0.100	2.300	0.396 ± 0.462	0.0100	0.900	-
Parameters	Units	Koh River			Beau Séjour Lake			WHO Guideline Values ^[19]
		Average ± SD	Min	Max	Average ± SD	Min	Max	
Chemical Parameters								
NH ₄ ⁺	mg/L	59.51 ± 50.90	5.520	197.10	19.69 ± 21.31	4.500	51.30	1.5 mg/L
NO ₃ ⁻	mg/L	148.82 ± 177.56	5.150	610.10	58.98 ± 65.58	10.40	170.10	50 mg/L
NO ₂ ⁻	µg/L	89.84 ± 153.38	8.360	531.58	20.59 ± 16.84	7.344	41.02	3 mg/L
PO ₄ ³⁻	µg/L	2582.53 ± 7250.46	13.54	27378.00	378.44 ± 421.72	65.60	843.80	5 mg/L
Total Phosphorus	mg/L	41.66 ± 19.71	12.20	84.00	37.86 ± 8.920	31.00	52.00	-
Heavy Metals								
Pb	mg/L	0.0038 ± 0.0071	0.0010	0.0283	0.0013 ± 0.0013	0.00002	0.0030	0.01 mg/L
Cd	mg/L	0.00042 ± 0.00097	0.00004	0.0038	0.00014 ± 0.00009	0.00005	0.00024	0.003 mg/L
Cr	mg/L	0.00033 ± 0.00026	0.00013	0.0012	0.00019 ± 0.00013	0.00005	0.00034	0.05 mg/L
Zn	mg/L	3.790 ± 2.954	0.452	10.40	1.990 ± 1.258	0.0590	3.190	3 mg/L
Cu	mg/L	1.351 ± 1.306	0.0240	5.140	1.338 ± 1.009	0.340	3.040	2 mg/L

3.1.5. Organic Pollution Index (OPI) Results

Table 7 presents the Organic Pollution Index (OPI) values calculated for the monitoring stations at Beau Séjour Lake and the Koh River. Overall, the OPI indicates a higher level of organic pollution in the river than in the lake, with pollution levels ranging from moderate to very high. In Beau Séjour Lake, monitoring points S2 and S3 show the most severely degraded levels (OPI = 2), corresponding to high pollution, whilst the other monitoring points remain at a moderate level of pollution (OPI = 3). In the Koh River, the most severely polluted stations are S5 (Pt Libreville-Domoraud), S8 (Camp Sea 1) and S10 (Abattoir), with OPI values of 1 to 1.5, indicating very high pollution. The upstream monitoring points (S1 to S9) are predominantly heavily polluted (OPI = 2), whilst the downstream monitoring points (S11 to S14, in the Lycée and KGB districts) show moderate pollution (OPI = 3).

Table 7. Organic Pollution Index (OPI) values and associated pollution levels for the monitoring stations at Beau Séjour Lake and the Koh River.

Stations	Sites	OPI Values	Indication
Beau Séjour Lake			
S1	Beau Séjour Lake	3	Moderate
S2		2	High levels
S3		2	High levels
S4		3	Moderate
S5		3	Moderate
Koh River			
S1	Si tu veux	2	High levels
S2	Blokoss	2	High levels
S3	Blokoss	2	High levels
S4	Pt Blokoss (CHR)	2	High levels
S5	Pt Libreville-Domoraud	1	Very high levels
S6	pt Dioulabougou-Domoraud	2	High levels
S7	Pt Saari UTB	2	High levels
S8	Camp Sea 1	1.5	Very high levels
S9	Camp Sea 3	2	High levels
S10	Abattoir	1	Very high levels
S11	Lycée	3	Moderate
S12	KGB	3	Moderate
S13	KGB	3	Moderate
S14	KGB	3	Moderate

3.1.6. Heavy Metal Pollution Index (HPI) Results

The assessment of metal contamination levels in water bodies was carried out using the Heavy Metal Pollution Index (HPI) method. To this end, the proportionality constant k was calculated on the basis of the WHO's maximum permissible values. Furthermore, the relative weights associated with each metal element were determined on the basis of the maximum permissible values (WHO) and the proportionality constant k . These various values are set out in **Table 8** for cadmium (Cd), lead (Pb), chromium (Cr), copper (Cu) and zinc (Zn).

Table 8. Relative weight and proportionality constant associated with each of the parameters used to calculate the HPI.

Parameters	WHO Maximum Permissible Level (Si)	1/Si	Wi
Pb ($\mu\text{g/L}$)	10	0.1	0.2201
Cd ($\mu\text{g/L}$)	3	0.33	0.7339
Cr ($\mu\text{g/L}$)	50	0.02	0.044
Cu ($\mu\text{g/L}$)	2000	0.0005	0.0011
Zn ($\mu\text{g/L}$)	3000	0.0003	0.0007
-	Σ	0.45417	1
-	$k = 1/\Sigma 1/Si$	2.20183	

Table 9 shows the heavy metal pollution index (HPI) values for the monitoring stations at Beau Séjour Lake and the Koh River. Overall, the level of heavy metal contamination remains low in both environments, with values well below the critical threshold of 100. Only monitoring station S1 on the Koh River ("Si tu veux" neighbourhood) stands out clearly, with an HPI of 154.9, indicating a high risk of contamination. All other monitoring stations, both in the lake and in the river, present a low risk.

Table 9. Heavy Metal Pollution Index (HPI) values and contamination risks.

Stations	Sites	HPI Values	Risk of Contamination
Beau Séjour Lake			
S1	Beau Séjour Lake	6.1	Low
S2		6.2	Low
S3		1.2	Low
S4		12.3	Low
S5		5.9	Low

Continued

Koh River			
S1	Si tu veux	154.9	High
S2	Blokoss	11.5	Low
S3	Blokoss	8.2	Low
S4	Pt Blokoss (CHR)	14.2	Low
S5	Pt libreville-domoraud	15.9	Low
S6	Pt Dioulabougou-Domoraud	7.8	Low
S7	Pt Saari UTB	3.5	Low
S8	Camp Sea 1	2.8	Low
S9	Camp Sea 3	10	Low
S10	Abattoir	10	Low
S11	Lycée	4.2	Low
S12	KGB	4.7	Low
S13	KGB	5.3	Low
S14	KGB	5.8	Low

3.1.7. Water Quality Index (WQI) Results

The water quality index (WQI) was used for the overall assessment of the water quality of the lake and the river. Initially, the proportionality constant k was determined on the basis of the limit values recommended by the World Health Organisation. Furthermore, the relative weights associated with each parameter used to calculate the WQI were calculated on the basis of the maximum limit values (WHO) and the proportionality constant k . The results obtained are presented in **Table 10**, specifically for temperature, pH, electrical conductivity, nutrients (NO_2^- , NO_3^- , PO_4^{3-} , NH_4^+), BOD_5 , and heavy metals (Zn, Cu).

Table 11 presents the Water Quality Index (WQI) values calculated for the monitoring points at Beau Séjour Lake and the Koh River. Overall, the WQI indicates severely degraded water quality, particularly in the river, where almost all monitoring points are classified as unsuitable. In Beau Séjour Lake, the most degraded monitoring points are S2 and S3, classified as unsuitable with very high WQI values (1070.3 and 661.9, respectively). Monitoring points S4 and S5 fall into the “very poor quality” category, whilst S1 is classified as “poor”. In the Koh River, the most degraded monitoring points are S10 (Abattoir, WQI = 4042.2), S6 (Pt Dioulabougou-Domoraud, WQI = 2293.6) and S1 (Si tu veux, WQI = 1654.7). Only the downstream monitoring point S14 (KGB) falls into the “very poor quality” category (WQI = 85.2).

Table 10. Relative weight and proportionality constant associated with each of the parameters used to calculate the WQI.

Parameters	WHO Maximum Permissible Level (Si)	1/Si	Wi
Temperature (°C)	30	0.033	0.015
pH	8.5	0.117	0.052
Conductivity (µS/Cm)	2000	0.0005	0.0002
NO ₂ ⁻ (µg/L)	3	0.33	0.15
PO ₄ ³⁻ (µg/L)	5	0.2	0.09
NH ₄ ⁺ (mg/L)	1.5	0.66	0.3
NO ₃ ⁻ (mg/L)	50	0.02	0.009
BOD ₅ (mgO ₂ /L)	40	0.025	0.011
Cu (mg/L)	2	0.5	0.224
Zn (mg/L)	3	0.33	0.15
-	Σ	2.23	1
-	$k = 1/\sum 1/S_i$	0.45	-

Table 11. Water Quality Index (WQI) values and quality classification for the monitoring stations at Beau Séjour Lake and the Koh River.

Stations	Sites	WQI Values	Quality Class
Beau Séjour Lake			
S1	Beau Séjour Lake	74.4	Bad
S2		1070.3	Contaminated water
S3		661.9	Contaminated water
S4		90.3	Very poor
S5		96.5	Very poor
Koh River			
S1	Si tu veux	1654.7	Contaminated water
S2	Blokoss	1119.6	Contaminated water
S3	Blokoss	1053.5	Contaminated water
S4	Pt Blokoss (CHR)	1596.5	Contaminated water
S5	Pt libreville-domoraud	621.2	Contaminated water
S6	Pt Dioulabougou-Domoraud	2293.6	Contaminated water
S7	Pt Saari UTB	734.8	Contaminated water

Continued

S8	Camp Sea 1	464.2	Contaminated water
S9	Camp Sea 3	1102.7	Contaminated water
S10	Abattoir	4042.2	Contaminated water
S11	Lycée	1732.6	Contaminated water
S12	KGB	155.1	Contaminated water
S13	KGB	128.2	Contaminated water
S14	KGB	85.2	Very poor

3.2. Discussion

The inventory of pollution sources in both environments highlighted that solid waste deposits represent the most frequent pressure, with an occurrence of 91.7% at the first twelve stations of the Koh River and 80% around Beau Séjour Lake. This predominance reflects a high exposure of water bodies to informal disposal practices near the banks. Accumulated waste can release leachate and, during run-off, transfer organic matter, nutrients, and other contaminants into the water [23] [24]. Their repeated presence can thus contribute to an increase in organic load and nitrogen compounds, while promoting a general deterioration of the physicochemical properties of the water [4] [5]. This situation is particularly concerning along the river, where the diversity of pollution sources is greater. The decrease in the average number of sources, from about three per station between S1 and S7 to about one per station between S8 and S14, suggests that the upstream and central sectors concentrate pressures more strongly. This spatial distribution is consistent with studies on the influence of urbanization and land use on surface water quality, which show that the intensification of human activities can locally exacerbate the pressures exerted on watercourses [2] [25].

The results of the OPI highlight significantly higher organic pollution in the Koh River, with low OPI values ($1 \leq \text{OPI} \leq 1.5$) indicating very high pollution at stations S5, S8, and S10, and high pollution throughout the upstream and central sector ($\text{OPI} = 2$), compared to moderate pollution downstream (S11 to S14, $\text{OPI} = 3$). In Beau Séjour Lake, the index shows moderate pollution levels except at stations S2 and S3. This contrast aligns with the high BOD5 and ammonium loads recorded in the river, particularly near the abattoir at S10. Domestic effluents, solid waste, and livestock activities can also be sources of organic matter and nitrogen likely to increase oxygen consumption, as illustrated by the low dissolved oxygen levels observed at the initial stations of the river (S1 - S9), and to promote the enrichment of the environment in nutrients [4] [5]. Nitrate levels frequently exceeding the WHO guideline value of 50 mg/L further reflect the importance of nitrogen inputs followed by their gradual transformation in the environment, particularly through nitrification processes [4] [24]. These enrichments are consistent with the diversity of sources identified along the river: solid waste deposits

(91.7% of stations), vegetable farming (75%), and connections from showers and septic tanks (58.3%), in addition to abattoir effluents partially responsible for the extreme degradation observed at S10 [26]. The increase in WQI values from S11 reflects an improvement in the river water quality, which could be explained by the reduction in the number of pollution sources per station as well as by the self-purification capacity of the watercourse [27] [28]. In the lake, the high pollution levels at S2 and S3 also correspond to the localized presence of waste deposits and livestock operations on these banks.

The HPI indicates overall low levels of metallic contamination in both environments, with all stations remaining below the critical threshold of 100, except for S1 on the Koh River (HPI = 154.9). This isolated value coincides with the temporarily high concentrations of lead and cadmium recorded at this station and reflects more of a localized situation than a generalized metallic contamination. The presence of mechanical and welding workshops in this area represents a potential source of metallic discharges, as these activities can contribute to the input of lead and cadmium in urban environments [23]. The absence of widespread exceedances in the lake as well as in the river confirms that heavy metals are not the main determinant of the degradation of the two environments. This situation contrasts with other aquatic systems subjected to greater anthropogenic pressures, in which indicators of metal pollution, notably the HPI, can reveal high levels of contamination [29].

The WQI finally confirms a severe overall degradation, particularly in the Koh River, where thirteen of the fourteen stations are classified as unfit, with extreme values at S10 (4042.2), S6 (2293.6), and S1 (1654.7); only S14, downstream, corresponds to the “very poor quality” category. In Beau Séjour Lake, only S2 and S3 are unfit; the other stations fall into the poor and very poor quality categories. Incorporating physico-chemical, chemical, and metal parameters, the WQI thus reflects the cumulative effect of all these parameters, illustrating the levels of degradation of the different hydrosystems [8]. The stations showing the highest WQI values generally correspond to those where the OPI indicates high levels of pollution. S10 represents the most pronounced case, with the influence of the slaughterhouse associated with significant organic degradation. Similarly, lake stations S2 and S3, characterized by the presence of waste and livestock, exhibit the highest levels of degradation in this environment according to the OPI. Thus, the results of the WQI tend to confirm a deterioration in water quality conditioned by various factors, namely the nature and distribution of pollution sources, hence the differences observed between the lake and the river. These observations remain consistent with studies conducted on aquatic environments in Côte d’Ivoire, which converge on the hypothesis of a significant influence of agricultural, domestic, livestock, and artisanal activities on water quality [30].

4. Conclusions

This study assessed the surface water quality of the Koh River and Beau Séjour Lake in Man using the organic pollution index (OPI), the heavy metal pollution index

(HPI), and the water quality index (WQI). The results show a more pronounced deterioration in the Koh River compared with Beau Séjour Lake.

The OPI reveals organic pollution ranging from moderate to very high, particularly pronounced at the upstream and mid-river monitoring stations (notably S5, S8 and S10). The HPI, meanwhile, indicates generally low metal pollution, with the exception of localised contamination at station S1. The WQI confirms this trend by classifying almost all of the river's stations as "unfit", whilst only certain stations on the lake (S2 and S3) reach this level of degradation.

These results are mainly attributable to the diversity and intensity of anthropogenic pollution sources, dominated by solid waste dumps, domestic discharges, market gardening, and livestock rearing and slaughtering activities. The gradual reduction in pollution pressures from upstream to downstream is reflected in a slight improvement in the indices at downstream monitoring points, though this does not yet allow for a return to satisfactory water quality.

The study concludes that organic pollution is the main factor contributing to the degradation of the water bodies studied. These findings highlight the need to improve solid waste and wastewater management in the city of Man, particularly along the Koh River, in order to minimise human-induced pressures and preserve the quality of these surface water resources.

Acknowledgements

The authors would like to express their gratitude to the Central Laboratories of the University of Man and Nangui Abrogoua University in Abidjan for their support with sample analysis. They would also like to thank the members of the Biotechnology and Environmental Engineering Research Unit of both universities for their collaboration and invaluable assistance during field data collection.

Author Contributions

Conceptualization & Methodology: F.M.Z., P.O.A., A.J.C.B., J.-M.P.O., and L.C.; Formal Analysis: P.O.A., F.M.Z., J.-M.P.O., and L.C.; Investigation & Data Curation: F.M.Z., P.O.A., and A.J.C.B.; Writing—Original Draft: P.O.A., F.M.Z., J.-M.P.O., and L.C.; Writing—Review & Editing: All authors; Project Administration & Supervision: F.M.Z., J.-M.P.O., and L.C. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] McGrane, S.J. (2016) Impacts of Urbanisation on Hydrological and Water Quality Dynamics, and Urban Water Management: A Review. *Hydrological Sciences Journal*, **61**, 2295-2311. <https://doi.org/10.1080/02626667.2015.1128084>
- [2] Shi, X., Mao, D., Song, K., Xiang, H., Li, S. and Wang, Z. (2024) Effects of Landscape

- Changes on Water Quality: A Global Meta-Analysis. *Water Research*, **260**, Article ID: 121946. <https://doi.org/10.1016/j.watres.2024.121946>
- [3] Onu, M.A., Ayeleru, O.O., Oboirien, B. and Olubambi, P.A. (2023) Challenges of Wastewater Generation and Management in Sub-Saharan Africa: A Review. *Environmental Challenges*, **11**, Article ID: 100686. <https://doi.org/10.1016/j.envc.2023.100686>
- [4] Nyenje, P.M., Foppen, J.W., Uhlenbrook, S., Kulabako, R. and Muwanga, A. (2010) Eutrophication and Nutrient Release in Urban Areas of Sub-Saharan Africa—A Review. *Science of the Total Environment*, **408**, 447-455. <https://doi.org/10.1016/j.scitotenv.2009.10.020>
- [5] Schnabel, B., Wright, S., Miller, R., Bryant, L.D., Kjeldsen, T.R., Maconachie, R., *et al.* (2022) Urban Surface Water Quality and the Potential of Phytoremediation to Improve Water Quality in Peri-Urban and Urban Areas in Sub-Saharan Africa—A Review. *Water Supply*, **22**, 8372-8404. <https://doi.org/10.2166/ws.2022.352>
- [6] Grace, S.F., Sadat, A., Rosine, Y.D., Bamory, O., Djezou, K.M. and Julien, C.K. (2026) Ecological Assessment of Physico-Chemical Factors Influencing the Diversity and Abundance of Cyanobacteria in Lakes of Côte d'Ivoire (Kan, Koubi, Loka, and Tiebissou). *FEMS Microbiology Ecology*, **102**, fiag035. <https://doi.org/10.1093/femsec/fiag035>
- [7] Kamelan, T.M., Diomandé, A., Kouamé, K.A. and Kouamélan, E.P. (2022) Spatio-Temporal Characterization of the Water Quality of the San Pedro River (Côte d'Ivoire, West Africa). *Journal of Biodiversity and Environmental Sciences*, **21**, 134-145.
- [8] Uddin, M.G., Nash, S. and Olbert, A.I. (2021) A Review of Water Quality Index Models and Their Use for Assessing Surface Water Quality. *Ecological Indicators*, **122**, Article ID: 107218. <https://doi.org/10.1016/j.ecolind.2020.107218>
- [9] Leclercq, L. and Maquet, B. (1987) Deux nouveaux indices chimique et diatomique de qualité d'eau courante. Application au Samson et à ses affluents (bassin de la Meuse belge). Comparaison avec d'autres indices chimiques, biocénotiques et diatomiques. Institut Royal des Sciences Naturelles de Belgique, Document de travail 38, 3-112.
- [10] Mohan, S.V., Nithila, P. and Reddy, S.J. (1996) Estimation of Heavy Metals in Drinking Water and Development of Heavy Metal Pollution Index. *Journal of Environmental Science and Health. Part A: Environmental Science and Engineering and Toxicology*, **31**, 283-289. <https://doi.org/10.1080/10934529609376357>
- [11] Singh, A., Prasad, S.M. and Singh, V.P. (2017) Assessment of Heavy Metal Contamination in Aquatic Environments. *Applied Water Science*, **7**, 2157-2166.
- [12] Horton, R.K. (1965) An Index Number System for Rating Water Quality. *Journal of Water Pollution Control Federation*, **37**, 300-306.
- [13] Brown, R.M., McClelland, N.I., Deininger, R.A. and Tozer, R.G. (1970) A Water Quality Index—Do We Dare? *Water Sewage Works*, **117**, 339-343.
- [14] Assemien François Yao, K., Ouattara, I., Coulibaly, L., Alex Jean-Martial Konan, K., Eugène Kouakou, K. and Blaise Yao, K. (2025) Flood Susceptibility Mapping Using GIS and Satellite Data: A Case Study of the Municipality of Man, Côte d'Ivoire. *American Journal of Environmental Protection*, **13**, 52-59. <https://doi.org/10.12691/env-13-3-1>
- [15] Institut National de la Statistique (2022) Recensement général de la population et de l'habitat 2021: Résultats globaux. INS.
- [16] Leclercq, L. (2001) Intérêt et limites des méthodes d'estimation de la qualité de l'eau. Station scientifique des Hautes-Fagnes, Document de travail, 44 p.

- [17] Gržinić, G., Piotrowicz-Cieślak, A., Klimkowicz-Pawlas, A., Górny, R.L., Ławniczek-Wałczyk, A., Piechowicz, L., *et al.* (2023) Intensive Poultry Farming: A Review of the Impact on the Environment and Human Health. *Science of the Total Environment*, **858**, Article ID: 160014. <https://doi.org/10.1016/j.scitotenv.2022.160014>
- [18] Amano, K.O.A., Danso-Boateng, E., Adom, E., Kwame Nkansah, D., Amoamah, E.S. and Appiah-Danquah, E. (2021) Effect of Waste Landfill Site on Surface and Ground Water Drinking Quality. *Water and Environment Journal*, **35**, 715-729. <https://doi.org/10.1111/wej.12664>
- [19] World Health Organization (2017) Guidelines for Drinking-Water Quality: Fourth Edition Incorporating the First Addendum. World Health Organization, 631 p.
- [20] Brown, R.M., McClelland, N.I., Deininger, R.A. and O'Connor, M.F. (1972) A Water Quality Index—Crashing the Psychological Barrier. In: Thomas, W.A., Ed., *Indicators of Environmental Quality*, Springer, 173-182. https://doi.org/10.1007/978-1-4684-2856-8_15
- [21] Zhou, W., Zhang, Y., Yin, J., Zhou, J. and Wu, Z. (2022) Evaluation of Polluted Urban River Water Quality: A Case Study of the Xunsi River Watershed, China. *Environmental Science and Pollution Research*, **29**, 68035-68050. <https://doi.org/10.1007/s11356-022-20297-9>
- [22] Camille, N., Mawa, K., Abdoulaye, D., Jeanne, O. and Laurent, Y. (2025) Polymetallic Contamination Assessment of Lake San-Pedro: Characterization by ICP-MS and Heavy Metal Pollution Index (HPI). *International Journal of Environmental Monitoring and Analysis*, **13**, 263-275. <https://doi.org/10.11648/j.ijema.20251305.13>
- [23] Müller, A., Österlund, H., Marsalek, J. and Viklander, M. (2020) The Pollution Conveyed by Urban Runoff: A Review of Sources. *Science of the Total Environment*, **709**, Article ID: 136125. <https://doi.org/10.1016/j.scitotenv.2019.136125>
- [24] Vaverková, M.D. (2019) Landfill Impacts on the Environment—Review. *Geosciences*, **9**, Article 431. <https://doi.org/10.3390/geosciences9100431>
- [25] Li, Y., Mi, W., Ji, L., He, Q., Yang, P., Xie, S., *et al.* (2023) Urbanization and Agriculture Intensification Jointly Enlarge the Spatial Inequality of River Water Quality. *Science of the Total Environment*, **878**, Article ID: 162559. <https://doi.org/10.1016/j.scitotenv.2023.162559>
- [26] Zahui, F.M., Beda, A.J.C., Ouattara, J.P., Messou, A. and Coulibaly, L. (2025) Environmental Impacts of Slaughterhouse Waste Management in Daloa and Man, Côte d'Ivoire. *Asian Journal of Biotechnology and Bioresource Technology*, **11**, 28-50. <https://doi.org/10.9734/ajb2t/2025/v11i4253>
- [27] Meybeck, M. and Helmer, R. (1989) The Quality of Rivers: From Pristine Stage to Global Pollution. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **75**, 283-309. [https://doi.org/10.1016/0031-0182\(89\)90191-0](https://doi.org/10.1016/0031-0182(89)90191-0)
- [28] González, S.O., Almeida, C.A., Calderón, M., Mallea, M.A. and González, P. (2014) Assessment of the Water Self-Purification Capacity on a River Affected by Organic Pollution: Application of Chemometrics in Spatial and Temporal Variations. *Environmental Science and Pollution Research*, **21**, 10583-10593. <https://doi.org/10.1007/s11356-014-3098-y>
- [29] Kumar, V., Parihar, R.D., Sharma, A., Bakshi, P., Singh Sidhu, G.P., Bali, A.S., *et al.* (2019) Global Evaluation of Heavy Metal Content in Surface Water Bodies: A Meta-Analysis Using Heavy Metal Pollution Indices and Multivariate Statistical Analyses. *Chemosphere*, **236**, Article ID: 124364. <https://doi.org/10.1016/j.chemosphere.2019.124364>

- [30] Adia, J.T., Yao, B.A.F., Soro, E.G., Briton, B.G.H., Goula, B.T.A., Kouakou, Y.S., *et al.* (2025) Impacts of Anthropogenic Activities on the Quality of Dam Lakes in Northern Côte d'Ivoire: The Case of the Korhogo, Boundiali and Katiola Dams. *Journal of Water Resource and Protection*, **17**, 530-548. <https://doi.org/10.4236/jwarp.2025.177027>